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Yield Losses From Sawmill Scanner Error

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Abstract

Most, if not all, optical scanners being used in sawmills are to some degree imprecise, inaccurate, or both. This scanner error results in lost yield through choice of the "wrong" sawing pattern, i.e., a pattern optimal for either a smaller or larger diameter log. The study reported here quantifies these losses and leads to the following recommendations.

(1) System designers should choose equipment and algorithms that minimize the possibility of measuring a log as being larger than it really is.

(2) System designers and sawmill personnel should attempt to keep measuring error as small as reasonably possible, especially in sawmills cutting small-diameter, short, low taper logs; e.g. stud mills.

(3) Anyone trying to determine the economic feasibility of achieving a particular level of scanner precision and accuracy in a specific sawmill can use this study as a prototype for quantifying the losses in that mill.

Keywords: Lumber, recovery, lumber yield, scanners, sawmilling, computer techniques, simulation, process control, automation, sawing patterns

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Yield Losses From Sawmill Scanner Error

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Introduction

The sawmill industry is using automated control systems to augment or, in some cases, replace human observation and decisionmaking. The rapid implementation of these systems for primary log breakdown has resulted from technological advances in optical scanners, computers, and simulation modeling. Even though scanners have been greatly improved, most, if not all, of those being used in sawmills are to some degree imprecise, inaccurate, or both. This imprecision and/or inaccuracy results in lost yield through choice of the "wrong" sawing pattern, i.e., a pattern optimal for a larger or smaller diameter log. There is no information available quantifying these losses; and, because most automated log breakdown control systems give reasonable results, many people in the sawmill industry do not realize a problem exists. Even where the problem has been recognized, without quantifying data it has been impossible to determine the economic feasibility of correcting it.

The results of the study discussed in this paper quantify the losses in lumber recovery resulting when the "wrong" sawing pattern is used by an automated log breakdown control system. This information can be used by sawmill managers and equipment manufacturers i determining specifications for new systems or modifications to existing ones.

Background

The basic elements of any automated control system include sensors, a decision model, actuators, and feedback. Sensors, such as optical scanners, measure the present state of the system. The decision model uses the information collected by the sensors and other data pertinent to the process being controlled to calculate the best processing decision, which actuators then implement. Finally, the results of the action are fed back for comparison with the processing decision or system variables. In closed-loop systems, the decision model uses feedback to automatically minimize variation in the results. In open-loop systems—which virtually all sawmill systems are—there is no automatic control. Instead the operator uses the feedback information to make adjustments in the system as he or she sees fit.

In a typical automated log breakdown control system, scanners measure the length and diameters of a log and determine its position with respect to the processing system. The decision model uses this information—along with mill parameters such as kerf, sawing variation, and product values—to determine the saw set and log position giving the highest yield. Setworks move the log or the saws or both to their proper positions, and the log is then sawn.

Usually the time required by the decision model to calculate the optimal sawing pattern and associated machine sets is too great to be able to make these calculations once the log has entered the processing system. Therefore, a primary log breakdown simulation model, such as the Best Opening Face (BOF) program (Lewis 1985), is used to calculate optimal sets for the entire expected range of logs, and these sets are stored in the control system computer. The model "looks up" the best set for each log based on the scanner measurements or operator decisions or both.

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Methods

The ability of an automated log breakdown control system to maximize recovery from each log is only as good as the information provided by the scanners. This information can be degraded by scanner imprecision and/or inaccuracy and by the algorithms used to convert scanner measurements into log end diameters.

Very little previous work has been published on the scanner error problem. Noffsinger (1979) found the accuracy of five different scanners ranged from 0.05 inch to 0.24 inch while the precision of the same scanners ranged from ±0.30 inch to ±2.14 inches. He did not consider how the scanner data might have affected lumber yields. No other work on this problem has been reported, although some mills may have developed proprietary information.

Computer simulation models have been used to study similar related problems. For instance, Hallock et al. (1976, 1978) and Stern et al. (1978) reported the relation of various sawing methods and sawing accuracy to lumber yield. In addition, the Sawmill Improvement Program (SIP) (Lunstrum 1974) has been used to evaluate the operating efficiency of over 800 sawmills and gives accurate predictions of possible recovery gains. Sawmill experience has shown the results of these various types of studies using simulation models are valid and useful in predicting sawmill performance. This suggests that the results reported in this paper also represent actual sawmill situations.

To study the effects of scanner error, I used the BOF model to simulate a well-operated North American sawmill converting small softwood logs into construction lumber. The logs, which the BOF model assumes are shaped like truncated cones, had small-end diameters ranging from 4.5 to 20.5 inches in 0.05-inch increments. Log lengths from 8 to 20 feet in 2-foot increments and taper from 1 to 5 inches per 16 feet of log length in 1-inch increments were used.

The sawmill parameters used, such as kerf, dressing allowance, and sawing variation (tables 1, 2), represented those used in the most advanced North American sawmills. These parameters were chosen after considering SIP studies, previous simulations (Hallock et al. 1976, 1978; Stern et al. 1978), and consultations with sawmill experts.

The two most common North American sawing methods were simulated (fig. 1). Logs were broken down into lumber and cants using the split taper sawing method, with the sawlines parallel to the pith, or the full taper sawing method, with the sawlines parallel to one side of the log (Hallock et al. 1976). In both cases, the resulting cants were broken down using the full taper method with a variable fence. Both 1- and 2-inch lumber were cut (table 2). However, the 1-inch lumber was cut only from the outside of the log and only when higher yield would result.

Table 1.—Sawing parameters used in simulation

Parameter	Value
Head saw kerf	0.165 inch
Resaw kerf	0.134 inch
Narrowest nominal width	4 inches
Shortest nominal length	8 feet
Shrinkage	3.3 percent
Wane allowance	25 percent

Table 2.—Lumber sizes and associated allowances used in simulation

Nominal	Dry dressed	Dressing allowance	Dressing shrinkage	Sawing variation	Rough green
			In.		
Thickness					
1	0.750	0.078	0.028	0.062	0.918
2	1.500	.078	.053	.062	1.693
Width					
4	3.500	.078	.120	.109	3.807
6	5.500	.078	.187	.109	5.874
8	7.250	.078	.246	.125	7.698
10	9.250	.078	.313	.125	9.765
12	11.250	.078	.381	.125	11.833

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Results

Even though use of the "wrong" sawing pattern results in loss of lumber recovery, it was not known whether this loss would be the same for all log diameters, lengths, and tapers. In order to quantify these effects the simulations were run in stages. Initially, 16-foot logs, 4.5 to 20.5 inches small-end diameter, with 2 inches of taper were considered. Each log was theoretically sawn by each sawing method using the BOF model and solutions based on maximum cubic recovery found. Then each log was theoretically sawn using sawing patterns for logs up to ±0.5 inch different in small-end diameter by 0.05-inch increments. Finally, the losses were calculated as a percentage of the BOF solution and the results plotted (fig. 2). Then sawing logs 8, 12, 16, and 20 feet in length, 4.5 to 20.5 inches in diameter, and with 2 inches of taper was simulated using both sawing methods. In addition, the sawing of logs 16 feet long, 4.5 to 20.5 inches in diameter, with 1 and 3 inches of taper was simulated using the split taper sawing method. Finally, since it was apparent length and taper affected yield, the sawing of logs in all length and taper classes was simulated using both sawing methods.

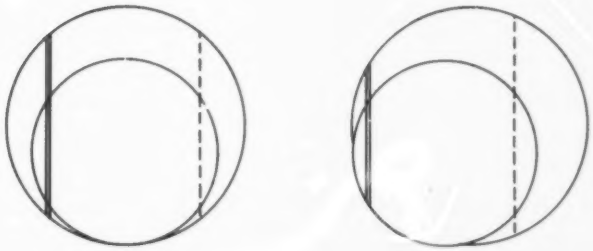

Figure 1.—Two methods of sawline orientation. (ML84 5623)

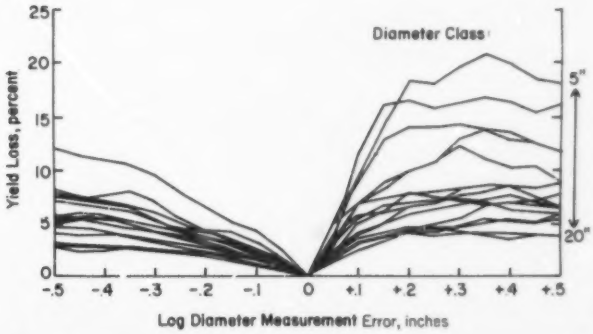

Figure 2.—Yield losses resulting from log diameter measurement error for 16-foot logs with 2-inch taper sawn by the split taper sawing method. One-inch-diameter classes from 5 to 20 inches are shown. (ML84 5617)

Several relationships are evident from the data. For almost every log, use of large-log sawing patterns resulted in greater losses than use of small-log sawing patterns (figs. 2-7; app.). In many cases, the loss for a given increment of error was over twice as great when the larger sawing pattern was used. It can also be seen that losses are generally greater with the full taper sawing method than with the split taper method and that small-diameter, short, and/or low taper logs have greater losses than large-diameter, long, and/or high taper logs (figs. 3-7; app.).

Sawing Methods

The data for 16-foot, 6-inch-diameter logs show that with split taper sawing, choosing a pattern for a larger log results in a maximum loss of 13.7 percent, while choosing a pattern for a smaller log results in maximum losses of 7.9 percent (fig. 3). For 16-foot, 18-inch-diameter logs split taper sawing results in maximum losses of 4.8 and 3.1 percent when choosing larger and smaller patterns respectively. With full taper sawing maximum losses for 6-inch logs are 18.7 and 13.2 percent while maximum losses for 18-inch logs are 13.2 and 3.1 percent (fig. 4).

Log Length

Considering log length, the maximum losses when split taper sawing 8-foot, 8-inch-diameter logs are 20.3 and 11.3 percent, while the maximum losses for 20-foot, 8-inch-diameter logs are 8.4 and 4.7 percent (fig. 5). In comparison, the maximum losses for 8-foot, 16-inch-diameter logs are 6.6 and 3.8 percent and for 20-foot, 16-inch-diameter logs are 3.1 and 2.9 percent (fig. 6).

Taper

The maximum losses when split taper sawing 16-foot logs with 1-inch taper are greater, 20.1 and 9.8 percent, than for 16-foot logs with 3-inch taper, 10.5 and 6.1 percent, and for 16-foot logs with 5-inch taper, 8.3 and 6.2 percent.

The losses due to 0.1- and 0.2-inch errors in sawing pattern selection for logs of all lengths, all taper classes, and selected diameter classes sawn by both sawing methods can be seen in the appendix. Because the BOF model saved no lumber shorter than 8 feet in length (table 1), the losses for 8-foot logs are the same for all taper classes.

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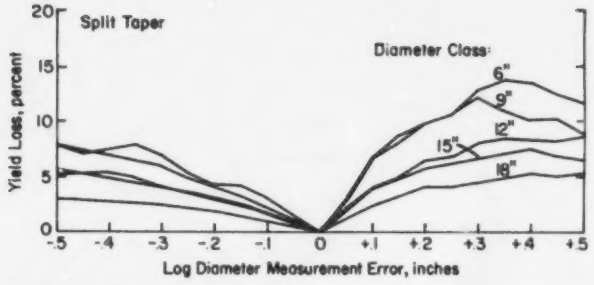

Figure 3.—Yield losses resulting from log diameter measurement error for 16-foot logs with 2-inch taper sawn by the split taper sawing method. (ML84 5618)

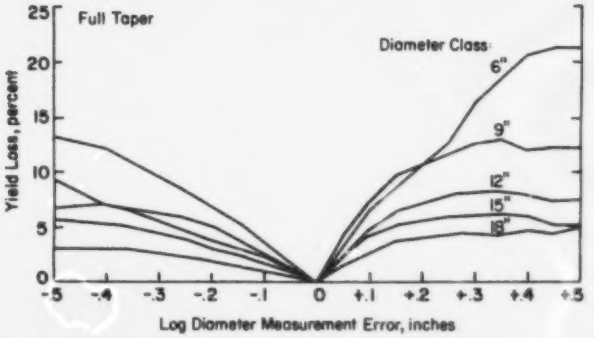

Figure 4.—Yield losses resulting from log diameter measurement error for 16-foot logs with 2-inch taper sawn by the full taper sawing method. (ML84 5619)

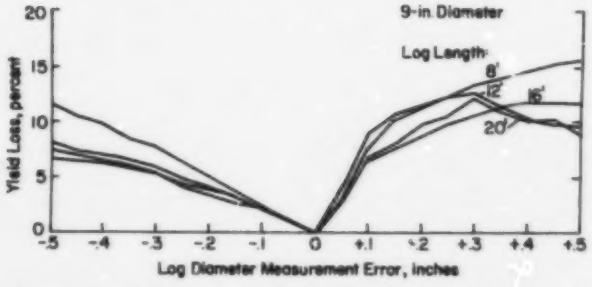

Figure 5.—Yield losses resulting from log diameter measurement error for 9-inch-diameter logs with 2-inch taper sawn by the split taper sawing methods. (ML84 5620)

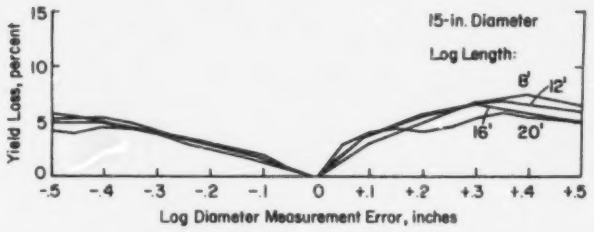

Figure 6.—Yield losses resulting from log diameter measurement error for 15-inch-diameter logs with 2-inch taper sawn by the split taper sawing method. (ML84 5621)

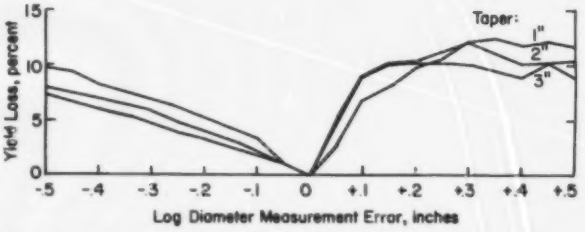

Figure 7.—Yield losses resulting from log diameter measurement error for 16-foot, 9-inch-diameter logs, sawn by the split taper sawing method. (ML84 5622)

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Conclusions

Because the logs modeled are assumed to be truncated cones and because the results are at least partly dependent on the assumed sawing parameters and log distribution, caution should be used in applying these findings to any specific mill. In particular, determining the economic feasibility of achieving a certain level of scanner precision and accuracy is not possible with current data. The magnitude of the losses shown in the appendix indicate that if Noffsinger's results (1979) are typical of the industry, the potential gains are large.

Even with these constraints, I can make several recommendations based on the present data.

(1) System designers should choose equipment and algorithms that minimize the possibility of measuring a log as being larger than it really is.

(2) System designers and sawmill personnel should attempt to keep measuring error as small as reasonably possible, especially in sawmills cutting small-diameter, short, low taper logs; e.g. stud mills.

(3) Anyone trying to determine the economic feasibility of achieving a particular level of scanner precision and accuracy in a specific sawmill can use this study as a prototype for quantifying the losses in that mill.

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Appendix

Yield losses resulting from 0.1- and 0.2-inch errors in sawing pattern selection for logs of selected diameter classes are shown in the following tables. Because the BOF model saved no lumber shorter than 8 feet in length, the losses for 8-foot logs are the same for all tapers.

Table A-1.—Yield losses due to log diameter measurement error for 8-foot logs

Diameter class	Split taper sawing method				Full taper sawing method			
	Yield loss for error size				Yield loss for error size			
	−0.2	−0.1	+0.1	+0.2	−0.2	−0.1	+0.1	+0.2
In.	*Pct*				*Pct*			
	ALL TAPERS							
6	10.0	4.6	15.3	21.2	10.0	4.6	15.3	19.6
8	5.2	2.6	9.8	16.6	5.2	2.6	11.2	16.6
10	3.8	1.8	7.9	11.5	3.8	1.8	8.2	12.1
12	3.7	1.8	3.8	6.7	3.7	1.8	3.4	6.4
14	2.9	1.5	4.3	5.8	2.9	1.5	4.5	6.0
16	2.1	1.2	2.9	5.7	2.2	1.1	3.2	5.6
18	1.9	1.0	2.6	3.4	1.9	1.0	2.7	3.4

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Table A-2.—Yield losses due to log diameter measurement error for 10-foot logs with various tapers

Diameter class	Split taper sawing method				Full taper sawing method			
	Yield loss for error size				Yield loss for error size			
	−0.2	−0.1	+0.1	+0.2	−0.2	−0.1	+0.1	+0.2
In.	*Pct*				*Pct*			
			1-INCH TAPER					
6	7.5	4.1	9.1	18.2	8.3	3.8	9.9	13.9
8	4.8	2.8	6.6	11.1	4.7	2.7	7.0	12.3
10	3.1	1.6	5.5	10.2	3.2	1.7	7.1	9.4
12	2.9	1.4	4.2	6.6	3.0	1.6	5.5	7.8
14	2.8	1.5	3.9	6.4	2.4	1.5	4.5	5.8
16	2.0	1.1	1.6	3.5	2.1	1.2	3.0	4.1
18	1.7	1.0	2.1	2.9	1.8	1.0	2.5	3.1
			2-INCH TAPER					
6	7.8	3.7	13.1	15.6	8.9	4.2	12.8	17.8
8	5.0	2.6	6.3	12.0	5.1	2.5	7.7	14.3
10	3.9	2.1	4.7	8.8	3.9	1.9	6.4	10.4
12	2.6	1.6	4.9	6.6	3.2	1.6	4.8	8.0
14	2.5	1.5	2.9	4.5	2.8	1.5	4.6	6.3
16	1.9	1.1	2.3	3.1	2.4	1.2	3.0	5.0
18	1.8	1.0	1.8	2.5	1.7	1.0	2.1	2.7
			3-INCH TAPER					
6	8.0	4.3	11.8	17.1	7.7	3.8	10.4	14.4
8	5.2	2.6	7.1	11.3	5.3	2.8	6.2	13.4
10	4.1	2.3	3.1	6.2	3.9	1.9	4.8	8.6
12	2.9	1.5	3.4	6.9	3.2	1.7	5.6	7.4
14	3.1	1.5	3.8	5.4	2.6	1.2	3.8	6.3
16	2.2	1.1	2.3	3.6	2.4	1.2	3.4	5.0
18	1.9	1.1	1.9	2.7	2.0	1.0	2.0	3.1
			4-INCH TAPER					
6	7.5	4.5	9.4	12.5	8.3	4.0	9.5	13.9
8	4.7	2.3	6.3	10.4	4.8	2.1	7.6	13.5
10	3.9	2.1	4.6	7.3	3.8	1.8	5.5	8.7
12	2.9	1.4	3.5	6.4	3.2	1.6	5.3	6.7
14	2.8	1.5	4.2	5.5	2.8	1.2	4.3	6.7
16	2.3	1.1	3.0	4.7	2.0	1.1	3.5	4.4
18	1.6	.8	1.9	2.7	1.8	1.1	2.0	3.6
			5-INCH TAPER					
6	7.5	3.9	7.2	13.2	8.2	3.5	7.4	17.8
8	4.7	2.5	8.1	9.7	4.5	2.4	6.9	11.5
10	3.5	1.9	5.1	9.8	3.6	1.9	5.8	9.2
12	3.1	1.5	4.8	8.1	3.1	1.5	4.1	6.6
14	2.7	1.5	4.0	5.6	2.4	1.3	3.2	4.5
16	2.0	1.0	3.3	4.8	2.1	1.1	3.2	5.0
18	1.7	.9	2.5	3.3	1.9	1.0	2.9	3.3

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Table A-3.—Yield losses due to log diameter measurement error for 12-foot logs with various tapers

Diameter class	Split taper sawing method				Full taper sawing method			
	Yield loss for error size				Yield loss for error size			
	−0.2	−0.1	+0.1	+0.2	−0.2	−0.1	+0.1	+0.2
In.	*Pct*				*Pct*			
			1-INCH TAPER					
6	5.7	3.3	9.4	15.1	7.9	4.2	11.7	17.1
8	4.1	2.2	5.8	11.2	4.5	2.6	8.1	12.4
10	3.3	1.8	5.5	9.2	2.9	1.9	6.3	10.4
12	2.4	1.3	3.9	5.3	2.7	1.4	5.8	7.9
14	2.5	1.4	3.1	5.6	2.5	1.5	4.2	5.7
16	2.0	1.1	1.7	2.9	2.1	1.2	3.1	3.9
18	1.5	.8	1.5	2.5	1.6	1.0	2.1	2.8
			2-INCH TAPER					
6	7.1	4.7	8.6	11.4	8.6	4.2	9.7	15.4
8	4.5	2.4	4.6	9.1	4.4	2.1	6.1	12.8
10	3.6	2.0	5.1	7.0	3.9	1.8	5.7	9.6
12	2.4	1.3	3.0	4.1	3.1	1.6	5.1	6.5
14	2.3	1.3	3.1	4.3	2.8	1.3	4.4	6.6
16	1.8	1.1	2.4	3.1	2.0	1.0	3.6	4.7
18	1.5	.9	2.0	2.5	1.6	1.0	2.0	2.8
			3-INCH TAPER					
6	7.2	3.2	9.2	13.5	7.4	3.6	10.1	14.3
8	4.4	2.2	5.2	9.5	4.5	2.0	4.5	11.1
10	3.2	1.8	3.5	5.6	3.5	1.8	5.1	9.4
12	2.4	1.4	3.9	6.1	3.1	1.5	4.5	6.8
14	2.3	1.0	2.7	4.3	2.7	1.5	3.3	5.0
16	2.0	1.1	2.5	4.2	2.2	1.2	2.6	4.4
18	1.3	.9	1.7	2.6	1.7	1.0	2.2	2.9
			4-INCH TAPER					
6	4.9	2.8	4.9	12.2	6.2	3.4	6.3	11.9
8	4.0	2.0	6.8	11.1	4.4	2.1	5.9	9.9
10	3.0	1.7	3.9	5.8	3.4	1.8	5.1	8.2
12	2.8	1.4	3.1	4.5	3.4	1.9	4.0	5.3
14	2.3	1.3	3.0	4.9	2.1	1.2	3.1	4.8
16	1.7	1.1	2.3	3.4	2.1	1.1	2.3	4.7
18	1.5	.9	2.2	2.9	1.6	.9	2.0	3.1
			5-INCH TAPER					
6	4.7	2.6	6.7	9.8	5.8	2.8	7.4	14.4
8	3.0	1.7	5.8	9.2	4.4	2.3	6.0	8.8
10	3.3	1.7	4.1	6.1	3.0	1.7	4.9	6.6
12	2.7	1.1	4.3	6.1	2.7	1.5	4.3	5.7
14	2.6	1.5	3.1	5.4	2.4	1.3	2.8	4.7
16	2.0	1.2	3.0	3.6	2.0	1.1	2.2	3.6
18	1.7	1.0	2.1	3.1	1.8	.9	2.1	2.9

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Table A-4.—Yield losses due to log diameter measurement error for 14-foot logs with various tapers

Diameter class	Split taper sawing method				Full taper sawing method			
	Yield loss for error size				Yield loss for error size			
	−0.2	−0.1	+0.1	+0.2	−0.2	−0.1	+0.1	+0.2
In.	*Pct*				*Pct*			
			1-INCH TAPER					
6	5.5	3.1	9.0	13.8	7.2	4.1	10.5	14.9
8	3.4	2.3	5.4	10.0	4.4	2.6	7.3	11.7
10	3.0	1.8	5.0	8.2	3.1	2.1	7.3	10.6
12	2.2	1.1	2.9	4.6	2.7	1.5	6.1	7.7
14	2.4	1.4	2.7	4.7	2.2	1.4	3.9	5.4
16	2.0	1.1	1.5	2.5	2.1	1.1	3.0	4.0
18	1.4	.8	1.6	2.3	1.6	.9	2.0	2.5
			2-INCH TAPER					
6	5.9	3.8	7.7	11.7	7.7	3.9	8.3	13.1
8	4.5	2.5	4.5	8.1	4.3	2.2	8.1	12.1
10	2.5	1.7	3.4	5.5	3.9	1.9	5.1	9.3
12	1.7	1.3	4.2	5.5	2.5	1.4	4.4	6.2
14	2.0	1.4	2.9	4.1	2.8	1.4	3.8	5.5
16	1.4	1.0	2.0	2.9	1.9	1.0	3.2	4.6
18	1.3	.8	2.1	2.6	1.5	.9	1.9	2.7
			3-INCH TAPER					
6	5.2	2.9	4.4	9.5	6.8	3.2	9.8	13.5
8	4.1	2.1	6.4	10.1	4.6	2.3	4.6	10.5
10	2.9	1.6	3.3	6.0	3.4	1.5	4.1	9.0
12	2.5	1.4	3.8	5.5	2.8	1.3	3.6	5.7
14	2.4	1.3	2.2	4.2	2.5	1.3	3.1	4.7
16	1.7	1.0	2.3	3.6	2.3	1.2	2.9	4.3
18	1.5	1.0	2.0	2.6	1.6	.9	2.1	2.7
			4-INCH TAPER					
6	4.2	2.0	5.0	9.2	6.3	3.4	6.3	20.1
8	3.4	2.0	4.9	7.6	3.7	1.8	4.0	7.5
10	3.2	1.5	3.9	6.8	3.6	1.8	4.4	7.7
12	2.7	1.4	3.8	4.9	2.9	1.6	4.1	5.9
14	2.5	1.5	2.6	4.5	2.6	1.3	3.2	5.0
16	1.9	1.2	2.4	3.0	1.9	1.0	2.5	4.1
18	1.6	.9	2.3	2.3	1.9	1.0	2.3	2.9
			5-INCH TAPER					
6	4.7	2.6	5.0	7.7	4.5	2.4	6.4	10.3
8	3.4	1.8	5.0	8.8	3.7	1.7	5.5	8.1
10	2.2	1.7	3.5	3.6	3.2	1.7	4.9	6.3
12	3.0	1.8	3.5	5.0	2.6	1.3	3.7	5.5
14	2.4	1.2	2.5	3.9	2.3	1.1	3.1	4.5
16	1.8	1.0	2.1	3.6	1.6	1.0	2.3	3.5
18	1.6	8	2.0	2.3	1.7	.9	2.0	2.7

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Table A-5.—Yield losses due to log diameter measurement error for 16-foot logs with various tapers

Diameter class	Split taper sawing method				Full taper sawing method			
	Yield loss for error size				Yield loss for error size			
	−0.2	−0.1	+0.1	+0.2	−0.2	−0.1	+0.1	+0.2
In.	*Pct*				*Pct*			
			1-INCH TAPER					
6	5.6	3.3	8.0	11.9	6.2	4.4	8.1	14.8
8	3.6	2.3	3.7	8.1	4.3	2.4	7.1	11.9
10	3.1	1.7	4.5	7.6	3.2	2.1	6.2	8.6
12	2.1	1.1	2.5	3.5	2.4	1.4	5.3	7.3
14	2.1	1.0	3.3	4.2	2.2	1.4	4.3	5.3
16	1.6	.8	1.7	2.6	1.7	1.1	3.4	4.2
18	1.3	.8	1.5	2.2	1.5	.9	1.8	2.5
			2-INCH TAPER					
6	4.2	3.1	6.7	9.8	6.9	3.5	7.5	11.1
8	3.6	2.2	3.4	6.9	4.4	2.2	5.4	10.5
10	2.8	1.6	3.0	5.6	3.0	1.5	5.1	7.6
12	2.0	1.2	3.4	4.8	2.7	1.3	4.6	6.3
14	1.9	1.1	2.7	4.3	2.4	1.3	3.6	4.7
16	1.5	1.0	2.0	3.0	1.9	1.0	2.7	3.6
18	1.2	.8	1.5	2.1	1.4	.8	1.7	2.6
			3-INCH TAPER					
6	4.6	2.5	3.9	9.1	6.3	3.6	6.0	15.8
8	3.5	1.9	5.0	7.9	3.6	1.6	4.2	7.9
10	3.3	1.8	3.5	7.0	3.4	1.7	4.9	7.7
12	2.4	1.3	3.6	4.6	2.5	1.2	3.6	5.7
14	2.2	1.4	2.4	4.0	2.3	1.3	2.5	4.4
16	1.9	1.1	2.2	2.9	2.1	1.1	2.4	4.2
18	1.3	.9	1.9	2.0	1.6	.9	2.2	2.6
			4-INCH TAPER					
6	5.3	3.1	3.9	7.7	5.5	2.7	6.2	11.4
8	3.9	2.1	3.1	7.0	4.3	2.0	4.9	8.2
10	3.3	1.7	3.1	5.5	3.4	1.5	4.4	7.3
12	2.7	1.5	2.9	4.1	2.7	1.4	4.3	6.1
14	2.0	1.0	1.8	3.6	2.2	1.2	2.5	3.8
16	2.0	1.0	1.9	3.1	2.0	1.0	2.1	3.7
18	1.4	.9	1.7	2.2	1.7	.9	2.1	2.4
			5-INCH TAPER					
6	4.9	2.6	4.3	7.8	4.8	3.2	4.2	16.3
8	3.7	1.8	4.3	6.8	3.3	1.5	4.7	7.7
10	1.6	1.7	2.7	2.7	3.0	1.7	3.7	6.2
12	2.5	1.5	2.9	3.7	2.4	1.1	2.8	4.5
14	2.1	1.2	2.0	3.7	2.3	1.1	3.1	4.0
16	2.1	1.2	2.0	2.8	2.0	1.1	2.5	3.7
18	1.6	.8	2.0	2.5	1.4	.8	1.8	2.4

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Table A-6.—Yield losses due to log diameter measurement error for 8-foot logs with various tapers

Diameter class	Split taper sawing method				Full taper sawing method			
	Yield loss for error size				Yield loss for error size			
	−0.2	−0.1	+0.1	+0.2	−0.2	−0.1	+0.1	+0.2
In.	*Pct*				*Pct*			
			1-INCH TAPER					
6	6.2	3.4	6.2	12.6	6.7	3.8	7.6	13.5
8	3.3	2.4	4.5	8.0	4.0	2.2	8.1	12.2
10	2.7	1.5	3.8	6.7	3.1	2.0	5.7	8.8
12	1.7	1.1	2.9	3.9	2.4	1.4	5.5	7.1
14	1.9	1.1	2.9	3.9	2.1	1.3	3.9	5.2
16	1.3	.7	1.6	2.3	1.8	1.0	3.2	4.1
18	1.2	.7	1.5	2.0	1.4	.8	1.9	2.8
			2-INCH TAPER					
6	3.4	2.3	5.1	9.6	5.9	3.2	6.4	11.7
8	3.2	1.9	3.9	7.3	4.6	2.1	4.9	9.4
10	2.4	1.5	3.7	6.3	2.6	1.5	4.2	7.1
12	1.9	1.1	3.6	5.6	2.4	1.3	4.0	6.1
14	1.6	1.2	2.6	4.0	2.3	1.3	3.4	4.8
16	1.4	.9	2.2	3.1	1.8	1.0	2.7	4.0
18	1.4	.9	1.7	2.3	1.6	.9	2.0	2.4
			3-INCH TAPER					
6	4.4	2.5	4.9	8.9	5.0	2.9	5.6	10.0
8	3.3	1.9	5.5	7.5	4.0	2.0	4.0	8.1
10	2.7	1.9	2.6	4.1	3.2	1.7	3.6	7.2
12	2.3	1.6	2.7	4.4	2.6	1.3	3.6	5.4
14	2.0	1.1	2.2	2.9	2.5	1.2	2.3	3.8
16	1.5	.9	1.5	2.4	1.8	.9	2.6	4.0
18	1.2	.7	1.6	2.0	1.6	.8	2.1	2.5
			4-INCH TAPER					
6	5.6	2.9	3.0	5.6	5.1	2.8	7.1	18.6
8	3.6	1.9	3.1	5.4	3.5	1.7	4.3	8.7
10	2.6	1.3	2.5	4.2	3.1	1.4	3.9	7.3
12	2.4	1.3	2.4	3.9	2.5	1.3	3.5	4.9
14	1.6	.9	1.7	2.7	1.9	1.0	2.8	3.9
16	1.7	1.0	1.6	2.5	1.8	1.0	1.8	3.1
18	1.6	.9	1.6	2.3	1.6	.9	2.0	2.6
			5-INCH TAPER					
6	4.9	2.8	2.9	4.3	4.6	2.9	5.6	9.6
8	2.6	1.6	4.0	5.0	3.1	1.8	4.2	5.6
10	2.2	1.7	3.0	3.1	2.8	1.4	2.8	5.5
12	2.3	1.2	2.8	4.0	2.3	1.3	2.6	4.2
14	2.2	1.1	1.9	3.2	1.9	1.1	2.3	2.6
16	1.8	.9	1.8	2.1	1.6	.8	2.0	2.7
18	1.5	.8	1.7	2.1	1.6	.9	1.7	2.6

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Table A-7.—Yield losses due to log diameter measurement error for 20-foot logs with various tapers

Diameter class	Split taper sawing method				Full taper sawing method			
	Yield loss for error size				Yield loss for error size			
	−0.2	−0.1	+0.1	+0.2	−0.2	−0.1	+0.1	+0.2
In.	*Pct*				*Pct*			
			1-INCH TAPER					
6	5.2	3.2	7.1	13.5	6.2	3.7	6.7	13.7
8	3.4	2.2	4.9	7.9	3.9	2.2	7.5	12.0
10	2.4	1.2	3.4	5.8	2.9	1.8	5.4	8.5
12	1.7	1.0	2.9	4.2	2.3	1.6	5.2	7.1
14	1.6	1.0	2.8	3.7	2.0	1.4	4.0	4.9
16	1.3	.7	1.6	2.5	1.7	1.0	3.2	4.1
18	1.3	.8	1.5	1.9	1.4	.8	2.0	2.7
			2-INCH TAPER					
6	3.7	2.0	3.6	8.6	6.1	3.4	5.4	14.4
8	3.3	1.7	4.1	6.9	3.8	2.1	4.5	8.0
10	2.4	1.8	2.9	6.8	3.0	1.6	4.2	7.8
12	2.0	1.0	3.8	5.0	2.5	1.3	4.3	5.9
14	2.1	1.1	2.2	3.7	2.3	1.2	2.9	4.4
16	1.4	1.0	2.4	2.7	2.0	1.1	2.8	3.6
18	1.3	.9	1.9	1.9	1.6	.9	2.3	2.6
			3-INCH TAPER					
6	5.7	2.9	2.8	6.6	5.0	2.4	6.1	12.9
8	2.6	1.4	3.3	6.3	3.9	2.0	3.6	7.2
10	2.6	1.3	2.3	4.1	3.2	1.8	4.7	7.2
12	2.3	1.3	2.6	3.7	2.4	1.3	4.1	5.4
14	2.1	1.0	2.6	3.4	2.0	1.1	2.2	4.0
16	1.4	.9	1.8	2.9	1.8	1.0	2.4	3.9
18	1.2	.7	1.4	1.8	1.5	.8	2.0	2.7
			4-INCH TAPER					
6	4.9	2.8	4.1	6.4	4.0	2.0	4.5	6.4
8	3.2	1.8	3.4	5.4	3.3	1.8	4.2	7.5
10	2.6	1.4	1.8	3.2	2.6	1.4	3.1	5.3
12	2.3	1.2	2.4	3.8	2.3	1.2	2.8	3.9
14	1.6	1.0	2.2	3.1	2.1	1.1	2.1	3.4
16	1.1	.8	1.1	1.9	1.5	.8	2.1	2.8
18	1.4	.8	1.6	2.0	1.6	.8	1.8	2.2
			5-INCH TAPER					
6	4.5	2.4	4.4	7.0	4.1	2.4	4.4	5.6
8	2.7	2.1	4.4	4.9	2.8	1.5	3.1	4.8
10	2.2	1.3	2.0	3.8	2.2	1.3	1.9	4.8
12	2.1	1.1	2.4	4.1	1.9	1.1	3.1	3.2
14	1.6	.9	1.9	2.5	1.8	1.0	2.3	2.7
16	1.5	.7	1.2	2.2	1.4	.8	1.5	2.9
18	1.2	.8	1.3	1.9	1.1	.6	1.4	2.3

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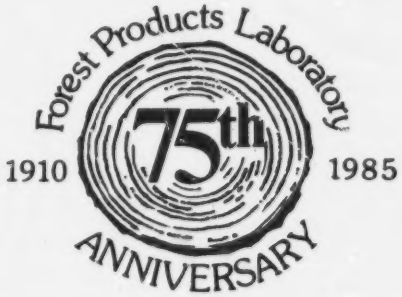
Early research at the Laboratory helped establish U.S. industries that produce pulp and paper, lumber, structural beams, plywood, particleboard and wood furniture, and other wood products. Studies now in progress provide a basis for more effective management and use of our timber resource by answering critical questions on its basic characteristics and on its conversion for use in a variety of consumer applications.

Unanswered questions remain and new ones will arise because of changes in the timber resource and increased use of wood products. As we approach the 21st Century, scientists at the Forest Products Laboratory will continue to meet the challenge posed by these questions.



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